(12) UK Patent Application (19) GB (11) 2 326 012 (13) A

(43) Date of A Publication 09.12.1998

(21) Application No 9811648.6

(22) Date of Filing 29.05.1998

(30) Priority Data
(31) 97022308 (32) 30.05.1997 (33) KR
(31) 97026861 (32) 24.06.1997
(31) 97051338 (32) 07.10.1997

(51) INT CL[6]
G02F 1/1343

(52) UK CL (Edition P)
G5C CA310 CA342 CA373 CHE

(56) Documents Cited
WO 97/39381 A1 US 4617646 A

(58) Field of Search
UK CL (Edition P) G5C CHE
INT CL[6] G02F 1/1343
ONLINE: EDOC WPI

(71) Applicant(s)
Samsung Electronics Co. Ltd.
(Incorporated in the Republic of Korea)
416 Maetan-dong, Paldal-ku, Suwon-City, Kyungi-do, Republic of Korea

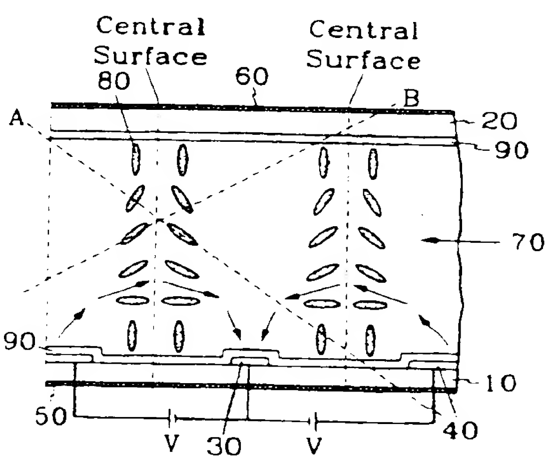
(72) Inventor(s)
Kyeung-Hyeon Kim
Seung-Boom Park
Jung-Uk Shim
Jang-Kun Song
Chang-Hun Lee
Nam-Heung Kim

(74) Agent and/or Address for Service
Marks & Clerk
57-60 Lincoln's Inn Fields, LONDON, WC2A 3LS, United Kingdom

(54) Abstract Title
Homeotropic liquid crystal display

(57) A liquid crystal device comprises two electrodes 30,40 parallel to each other formed on one 10 of two substrates 10,20, homeotropic alignment films 90 formed on the substrates and a liquid crystal material 70 having positive dielectric anisotropy injected between the substrates. When a voltage V is applied to the two electrodes, a parabolic electric field between the electrodes drives the liquid crystal molecules. Since the generated electric field is symmetrical with respect to the boundary-plane equidistant from each of the two electrodes, the liquid crystal molecules 80 are symmetrically aligned with respect to the boundary-plane, and the optical characteristic is compensated in both regions divided by the boundary-plane, thereby obtaining a wide viewing angle. The electric field does not exert any influence on the liquid crystal molecules on the boundary-plane since the electric field on the boundary-plane is parallel to the substrate and perpendicular to the two electrodes; and thus, it is perpendicular to the liquid crystal molecules. The device also comprises means for varying directions of long axes of molecules of the liquid crystal layer, wherein the layer has at least two adjacent regions, the molecules of any one region being aligned in the same direction, and the molecules of two regions are aligned symmetrically with respect to the plane-boundary of the regions. The parallel electrodes in each pixel unit may be bent, and in adjacent pixels may be in different directions.

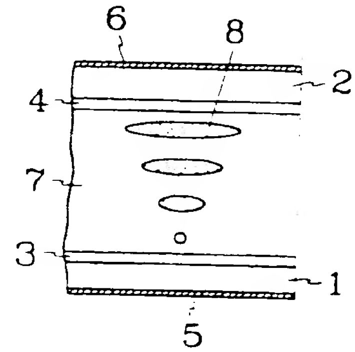
FIG.2B



When voltage is applied

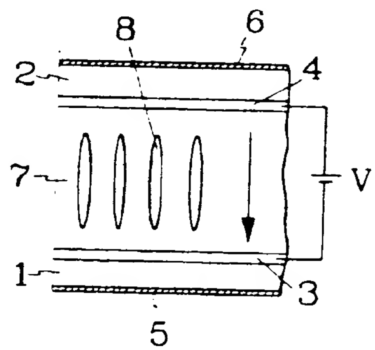
GB 2 326 012 A

FIG.1A (Prior Art)



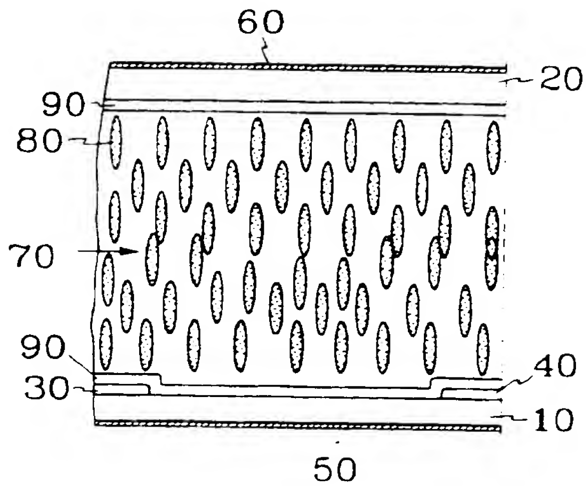
When voltage is not applied

FIG.1B (Prior Art)



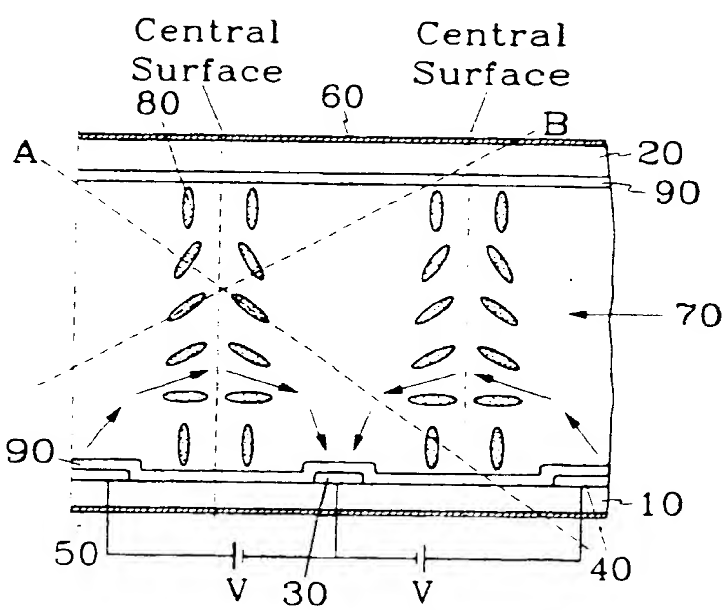
When voltage is applied

FIG.2A



When voltage
is not applied

FIG.2B



When voltage
is applied

FIG.2C

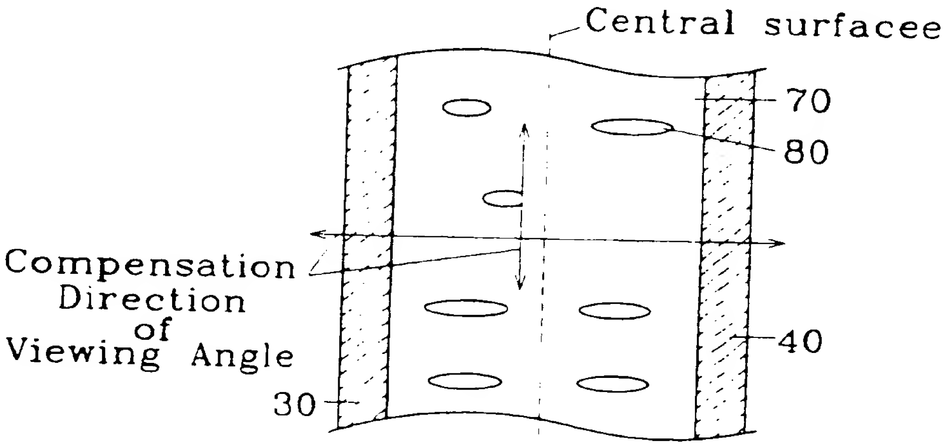

Central surfacee
70
80
Compensation
Direction
of
Viewing Angle
40
30

FIG.3C

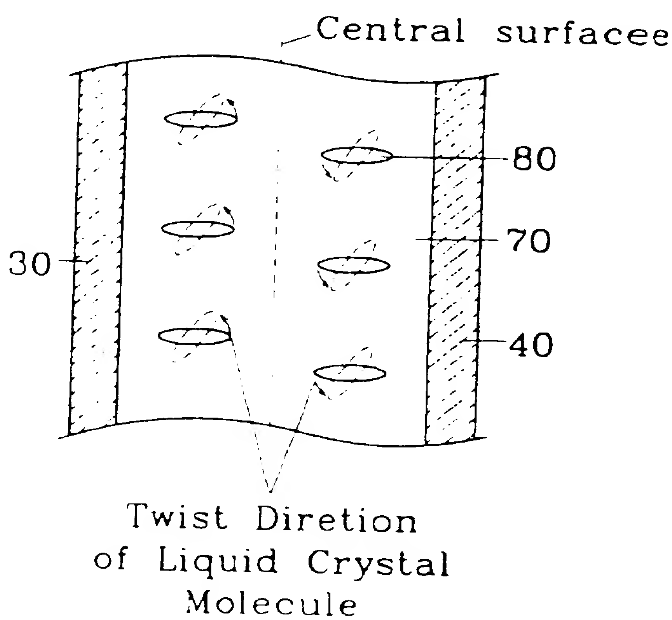
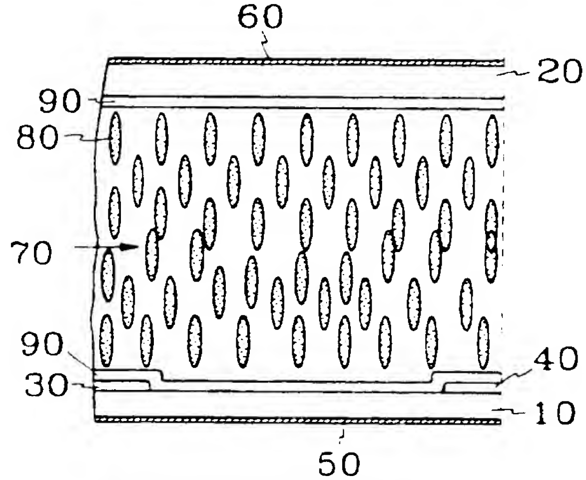
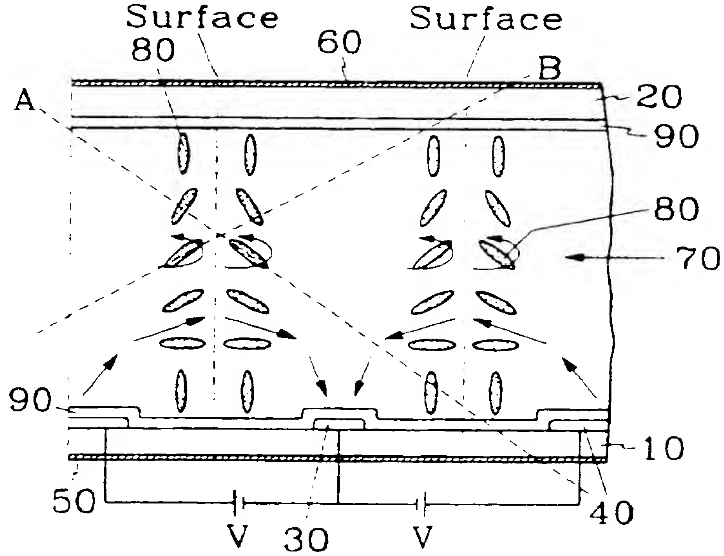

Central surfacee
80
30
70
40
Twist Diretion
of Liquid Crystal
Molecule

FIG.3A



When voltage
is not applied

FIG.3B



When voltage
is applied

FIG.4

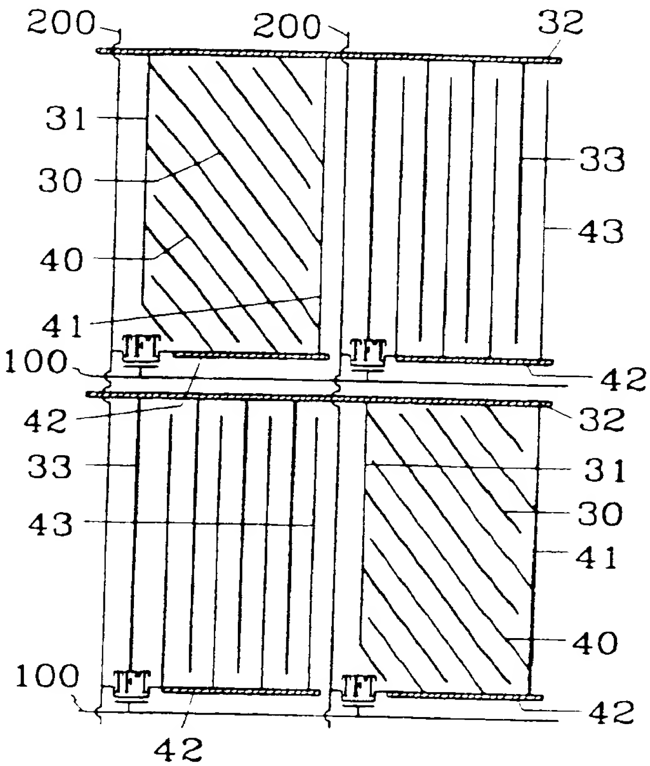
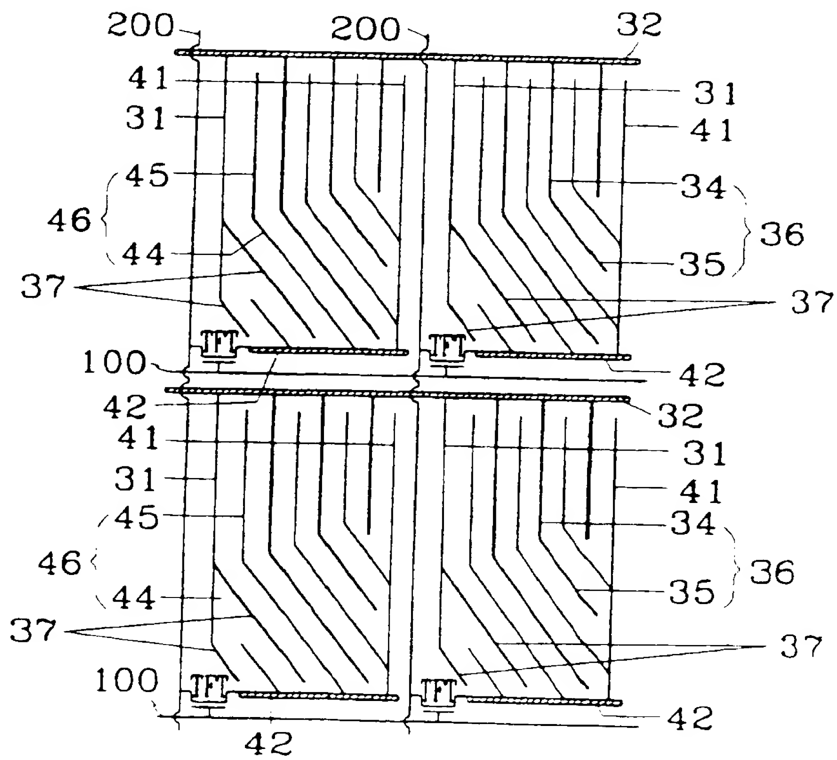

200
200
32
31
33
30
43
40
41
TFT
TFT
100
42
42
32
33
31
43
30
41
40
100
TFT
TFT
42
42

FIG.5


200
200
32
41
31
31
41
45
34
46
36
44
35
37
37
TFT
TFT
100
42
42
32
41
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46
36
44
35
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37
100
TFT
TFT
42
42

FIG.6

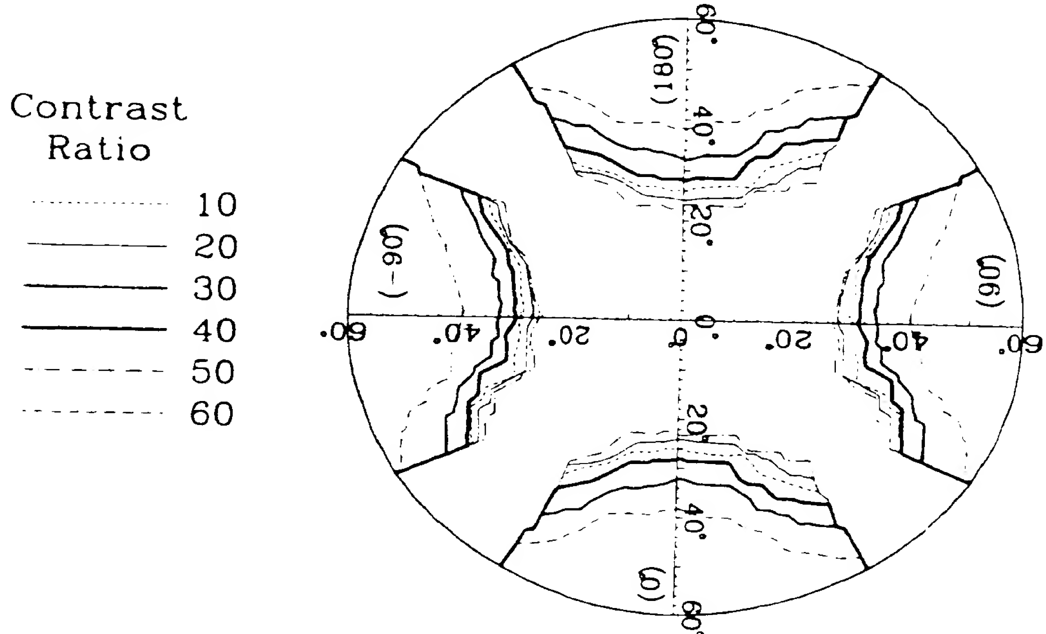

Contrast Ratio
10
20
30
40
50
60

FIG.7

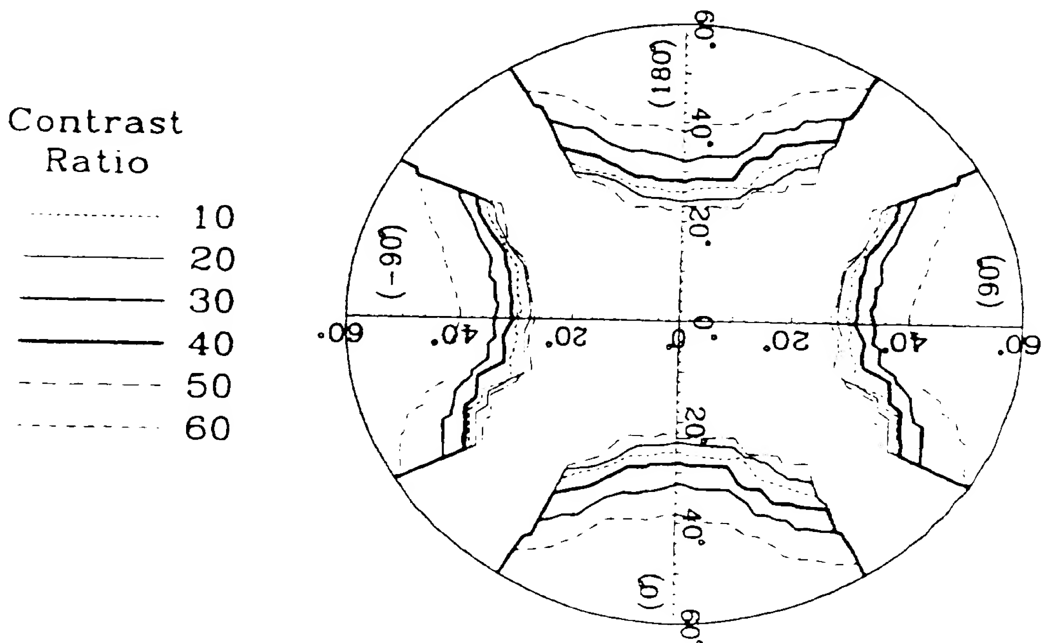

Contrast Ratio
10
20
30
40
50
60

FIG.8

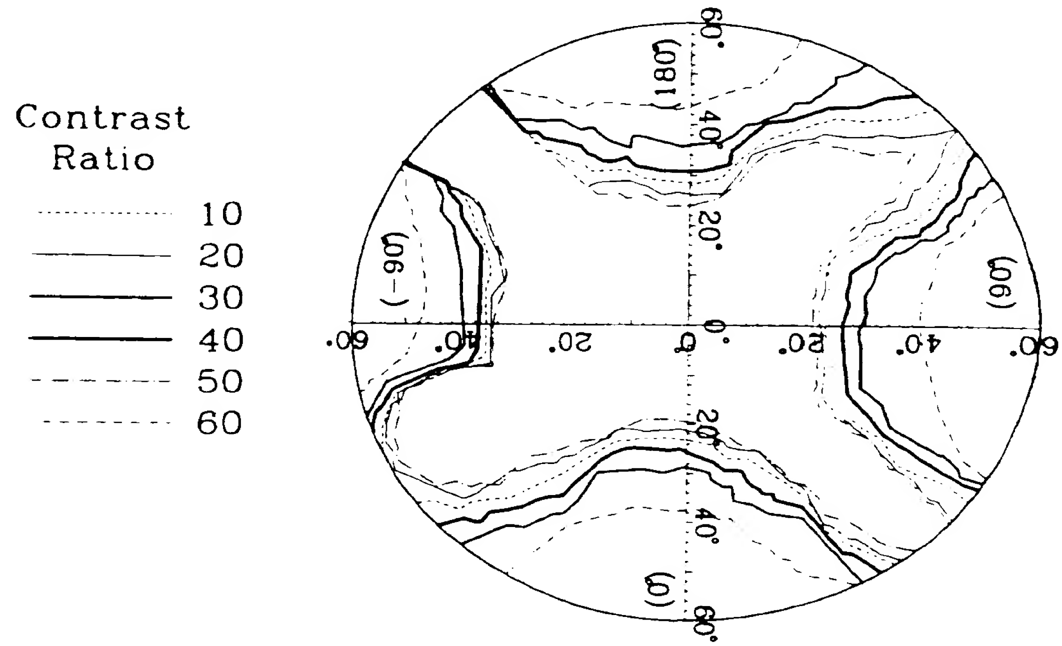

Contrast Ratio
10
20
30
40
50
60
60°
(180°)
40°
20°
0°
20°
40°
60°
(0°)
(-90°)
(90°)

FIG.9

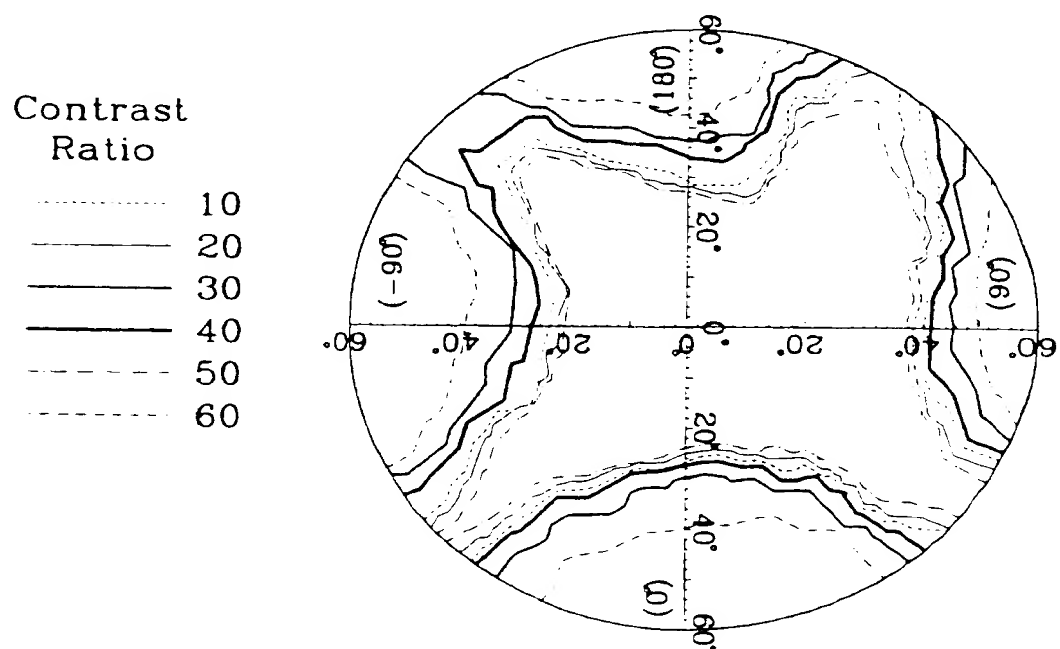

Contrast Ratio
10
20
30
40
50
60
60°
(180°)
40°
20°
0°
20°
40°
60°
(0°)
(-90°)
(90°)

FIG. 10

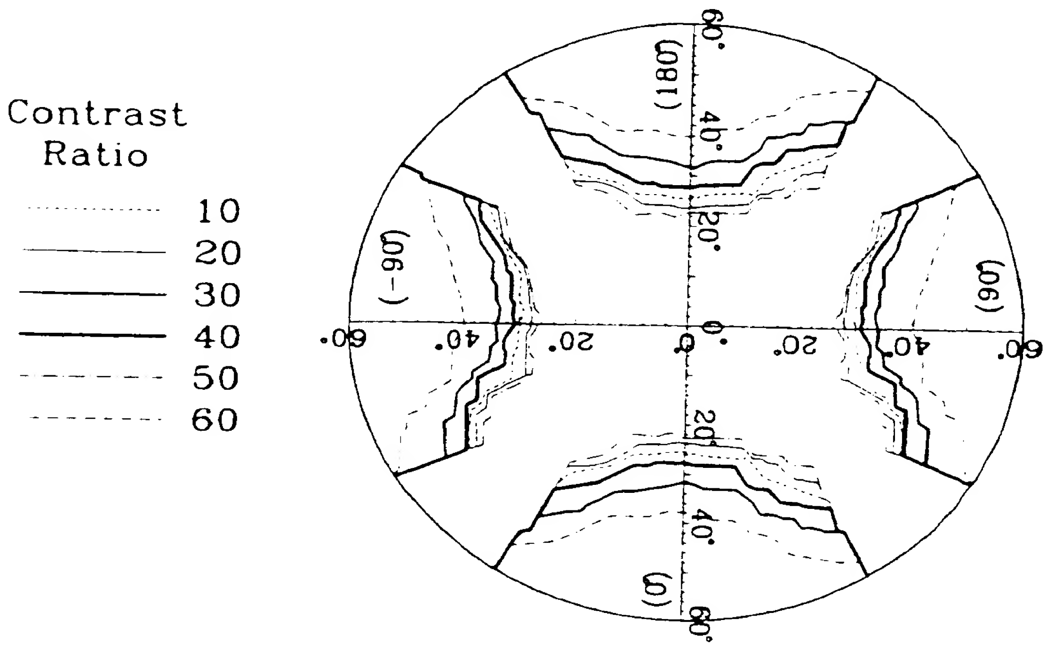

Contrast
Ratio
10
20
30
40
50
60

FIG. 11

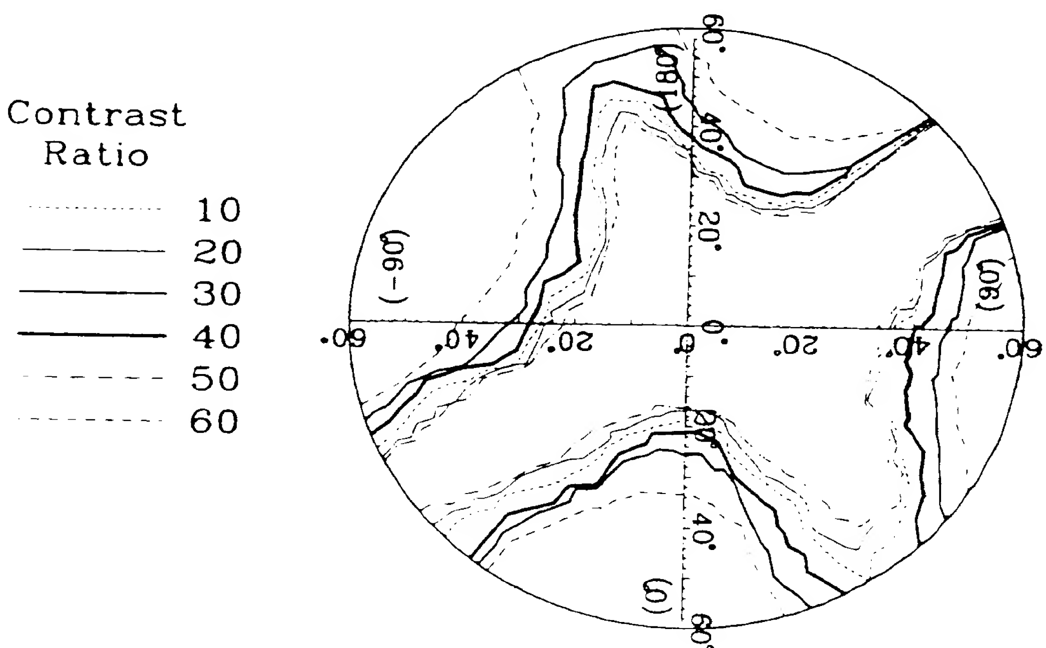
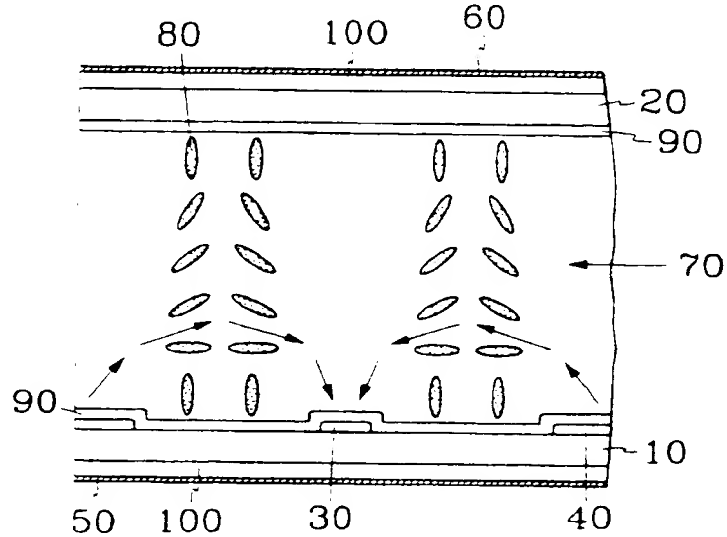

Contrast
Ratio
10
20
30
40
50
60

FIG. 12



10/20

FIG. 13

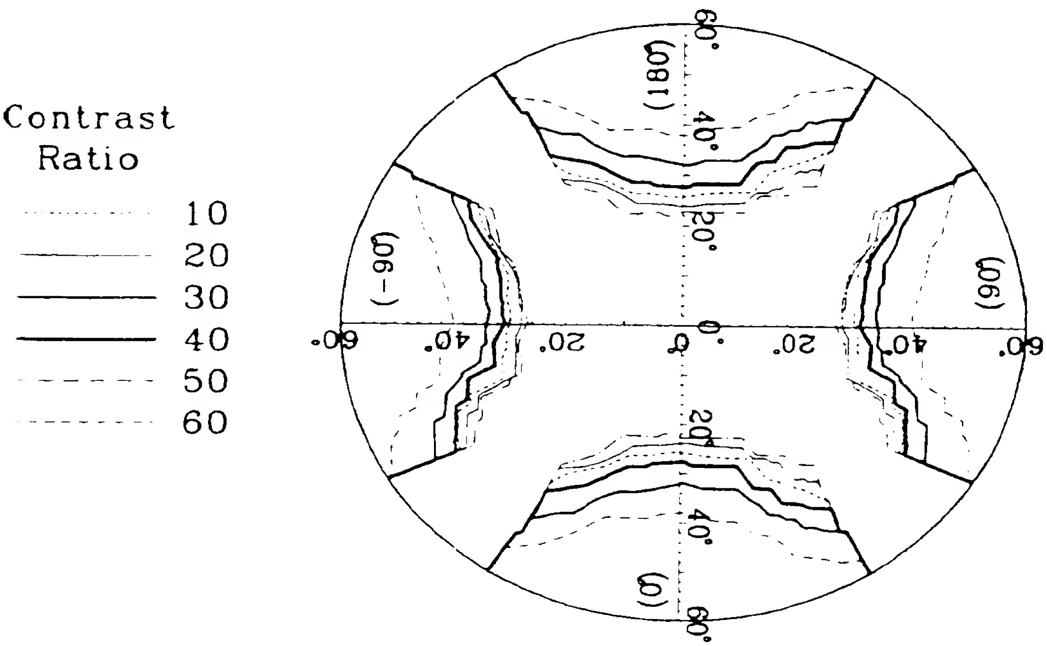


FIG. 14

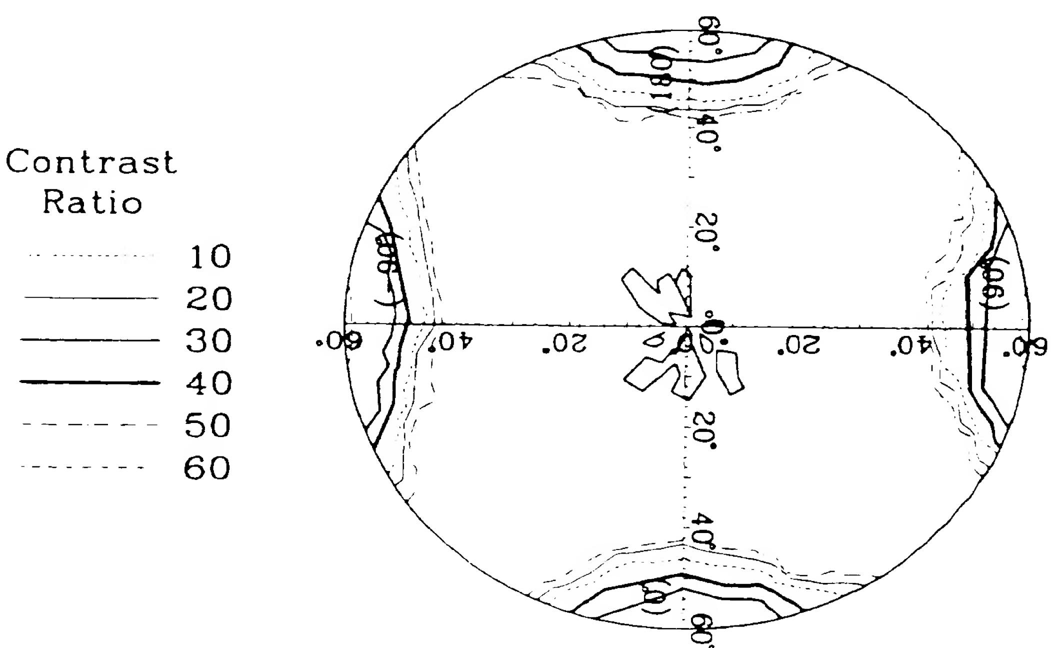


FIG. 15

Contrast Ratio

···········	10
———	20
———	30
———	40
– – – –	50
- - - -	60

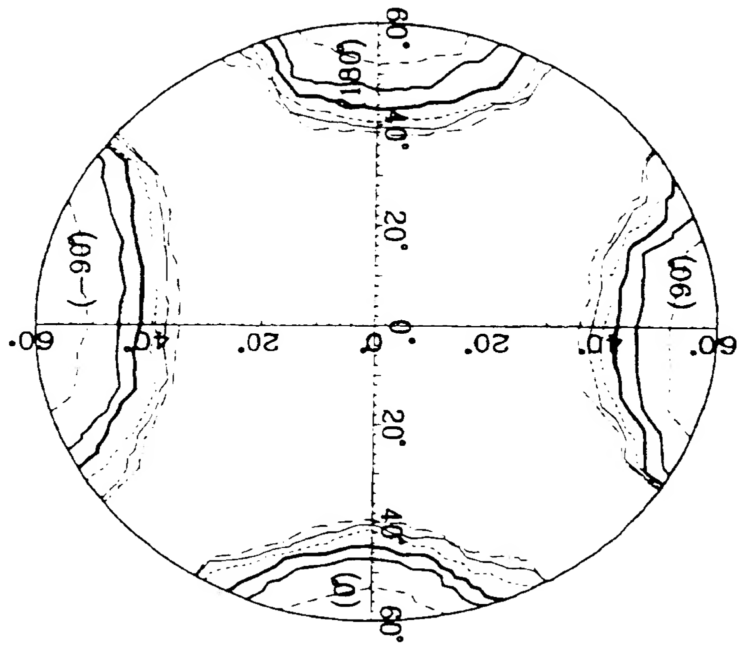


FIG. 16

Contrast Ratio

···········	10
———	20
———	30
———	40
– – – –	50
- - - -	60

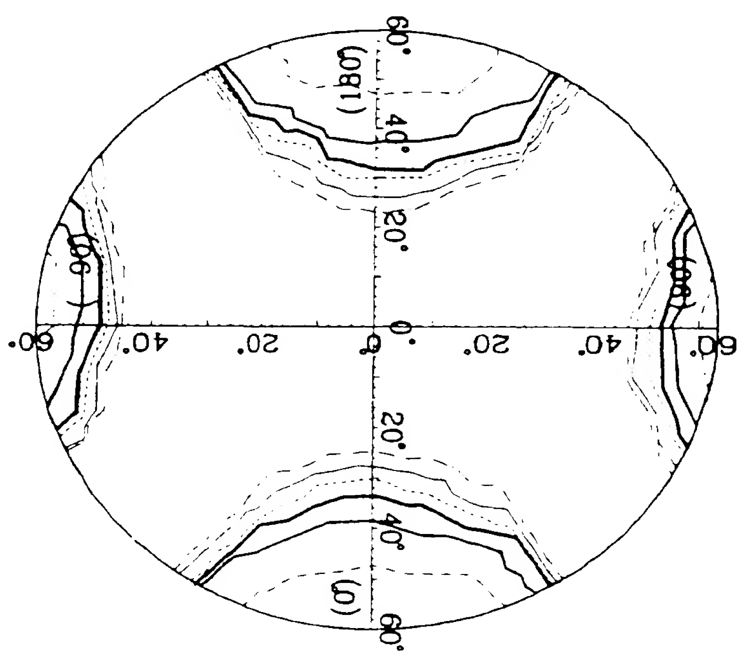


FIG. 17

Liquied Crystal Cell gap(μm)	Distance between Electrodes (μm)	V_{max} (V)	T_{max} (%)	t_{on} (msec)	t_{off} (msec)	t_{tot} (msec)	V_{10} (V)	V_{90} (V)
3	8	30.0	17.4	52.1	9.7	61.8	5.5	18.7
4	8	15.0	14.1	28.9	12.9	41.8	3.7	8.6
5	8	8.0	12.3	23.2	15.7	38.9	3.1	5.9
6	8	6.0	11.0	19.7	19.6	39.3	2.8	4.8
6	10	6.2	12.7	32.9	21.5	54.4	3.1	5.0

FIG. 18

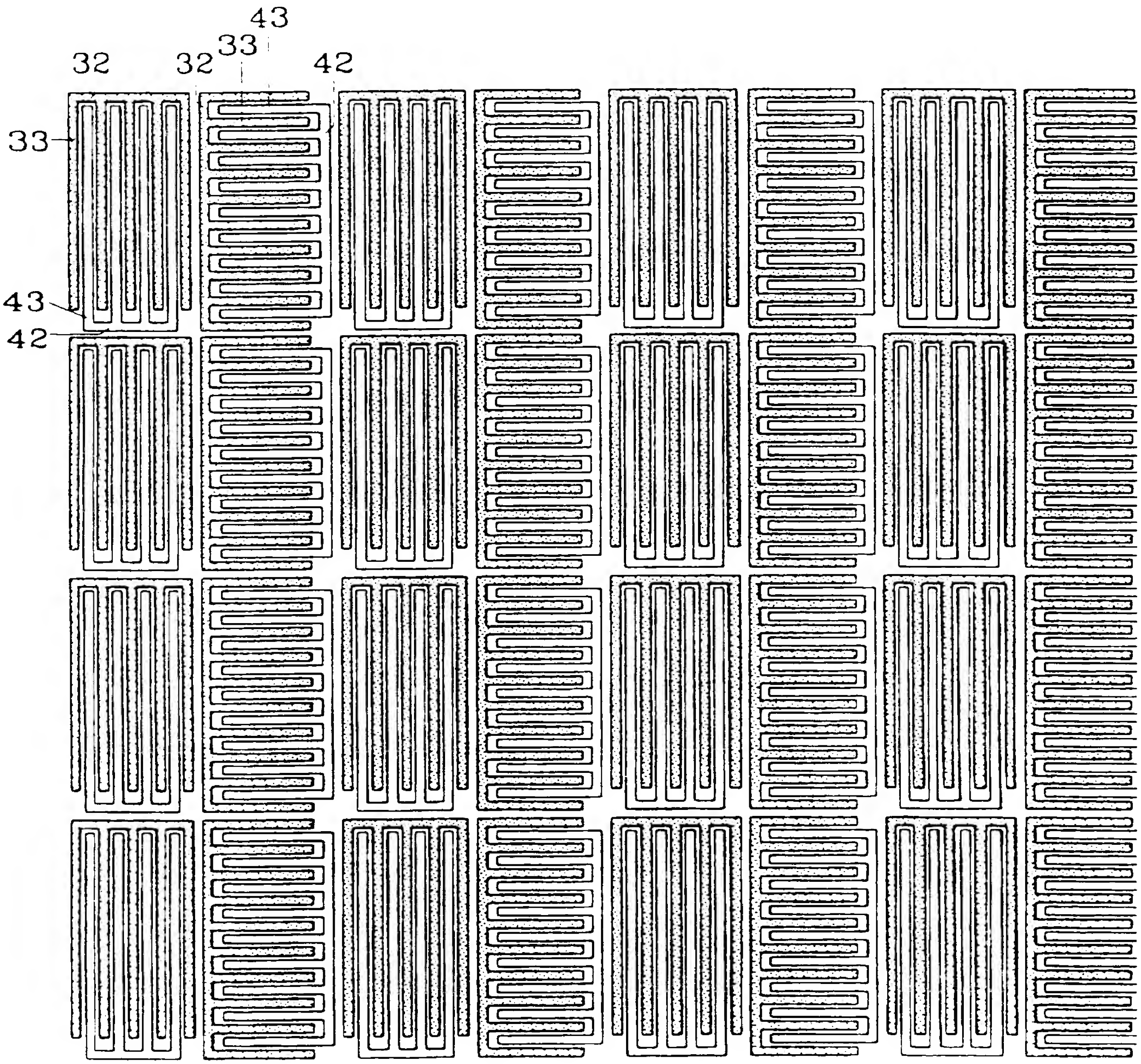


FIG.19

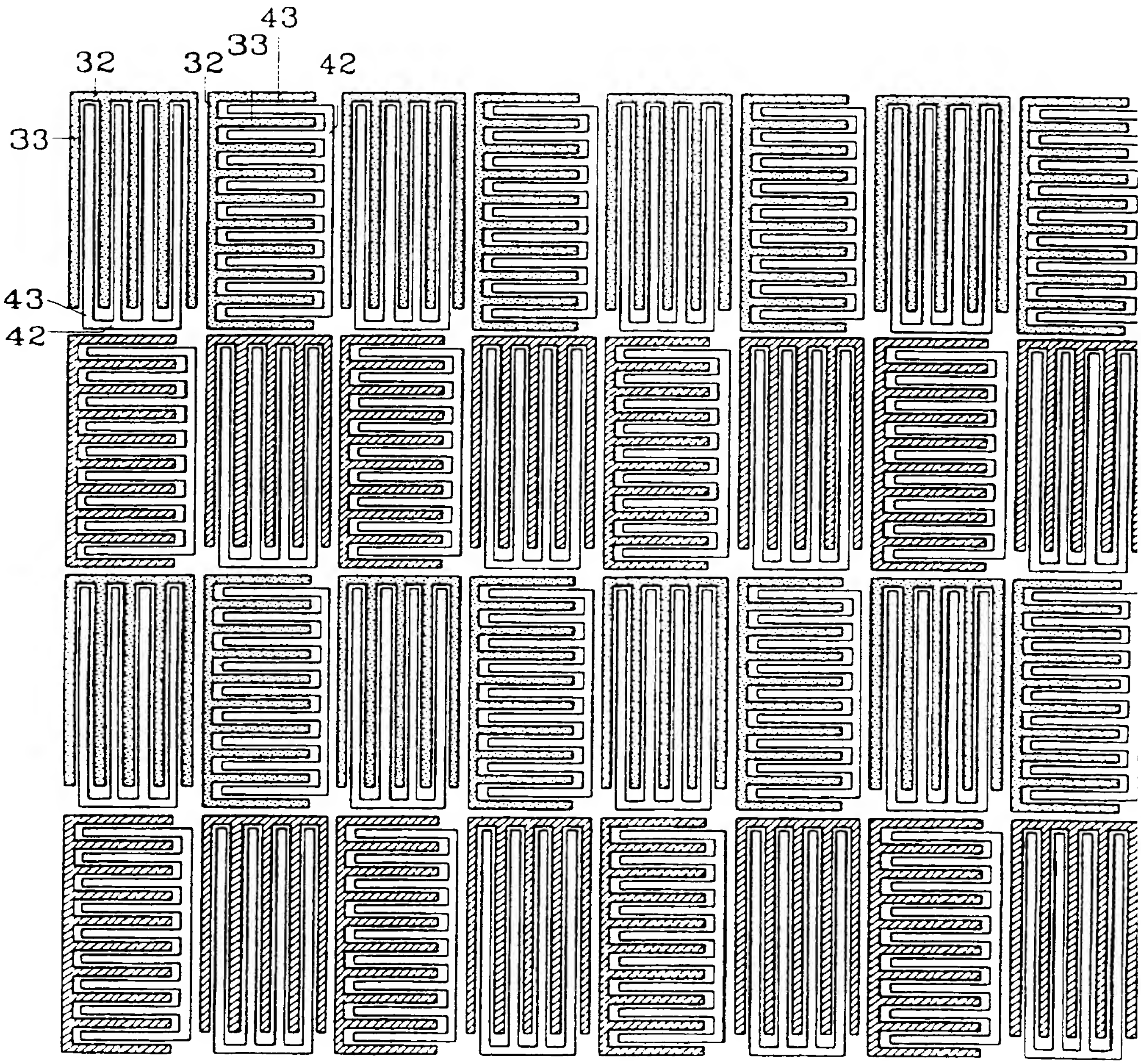


FIG.20

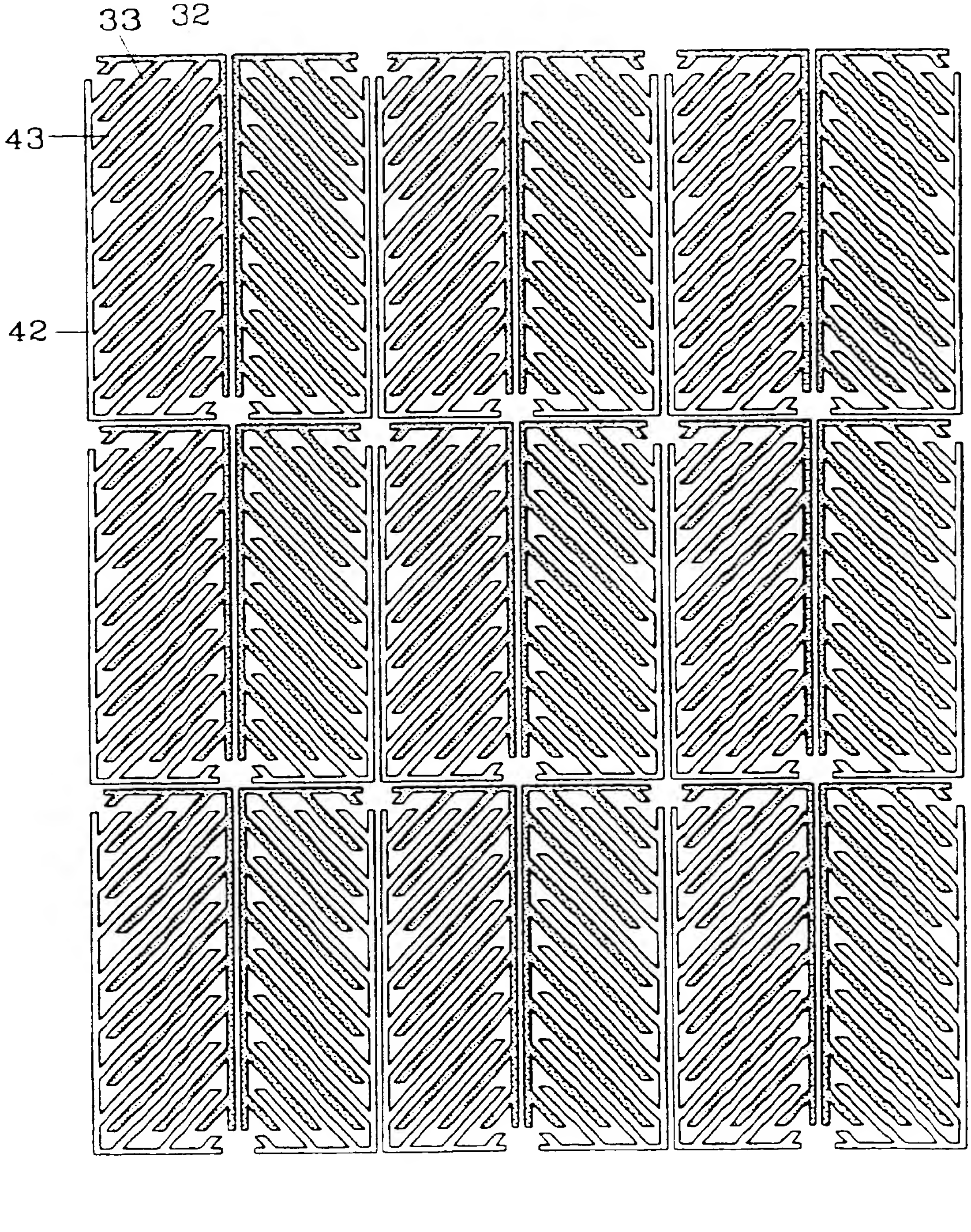


FIG.21

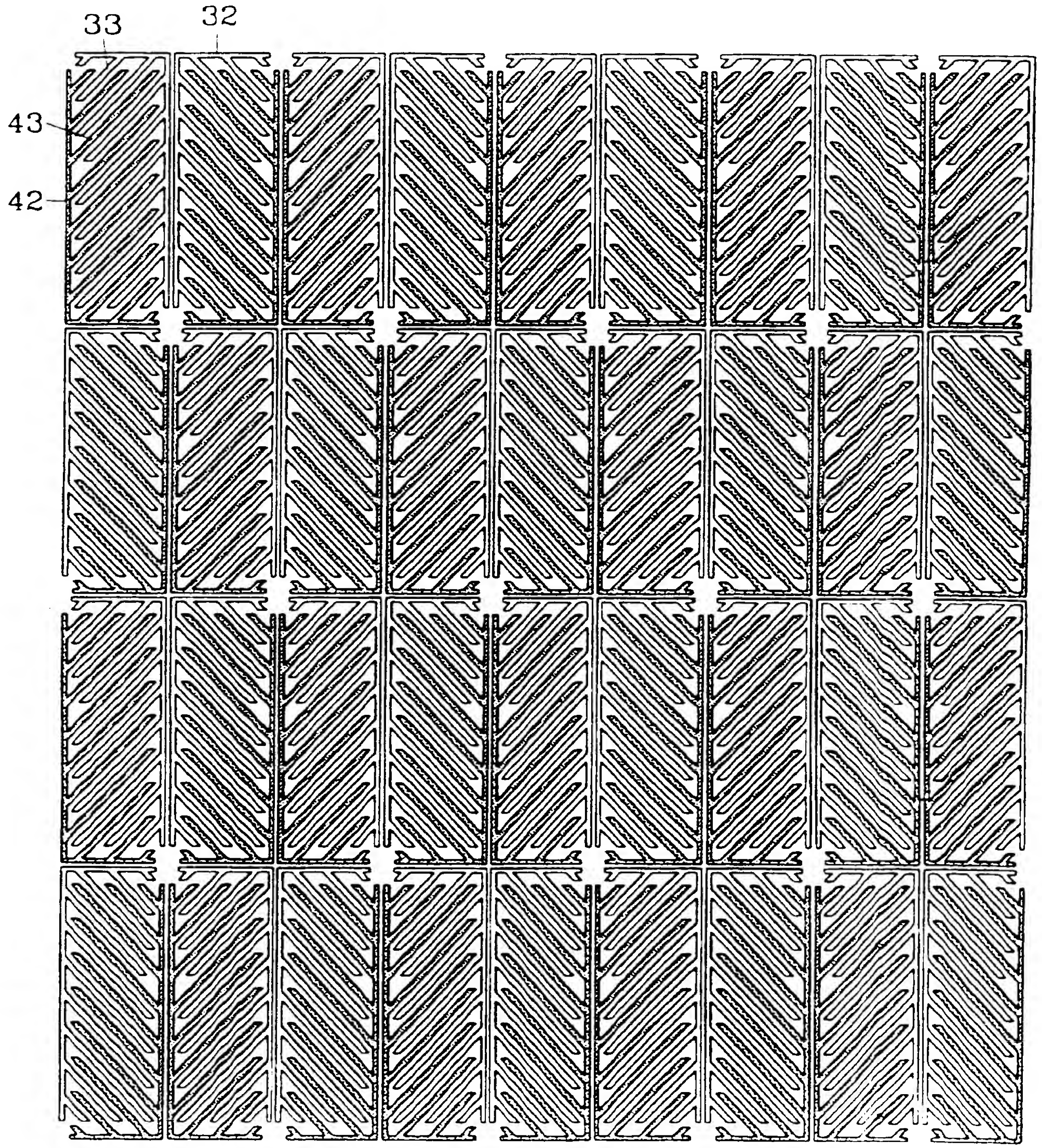
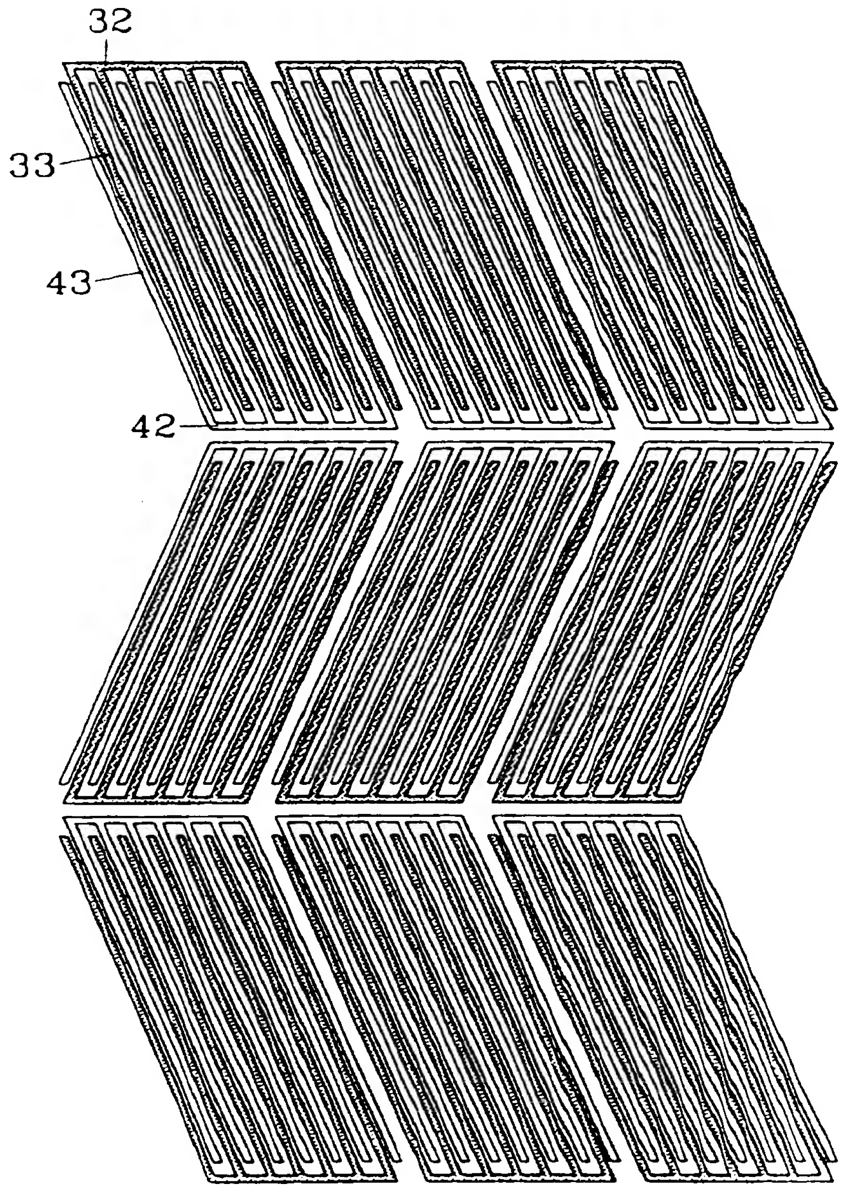


FIG.22



18/20

FIG.23

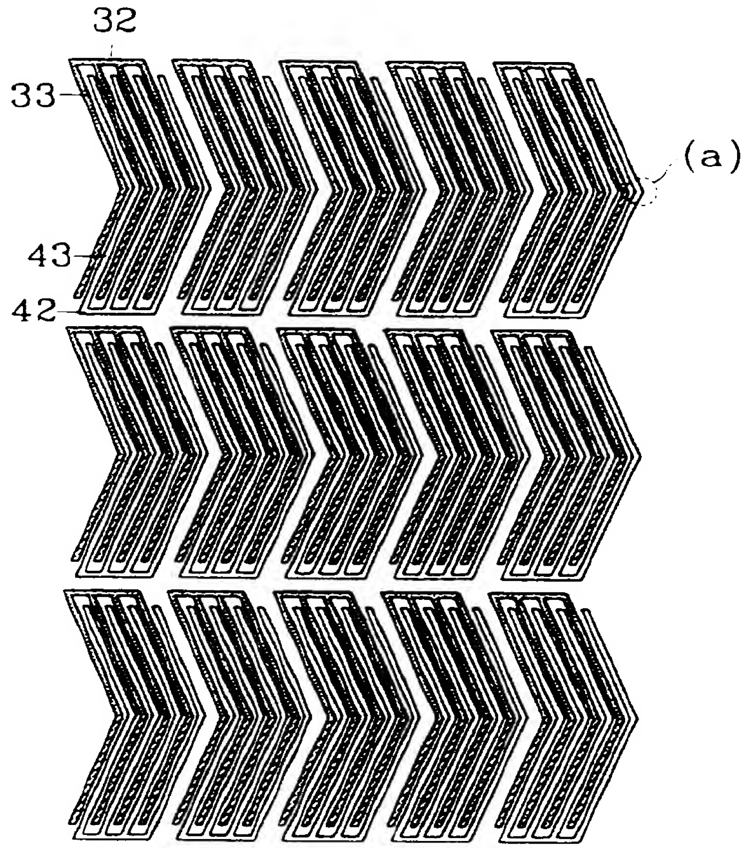


FIG.24

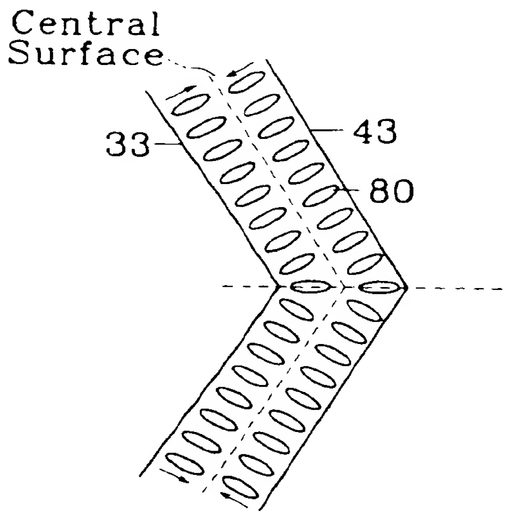


FIG.25

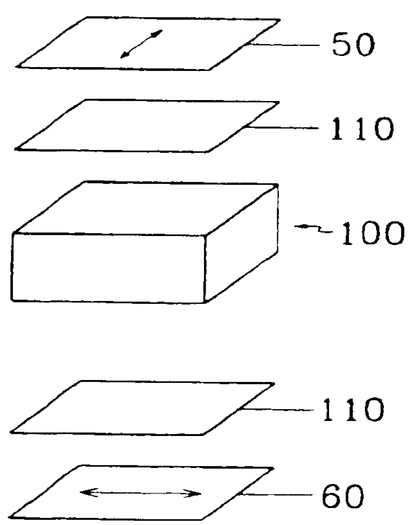


FIG.26A

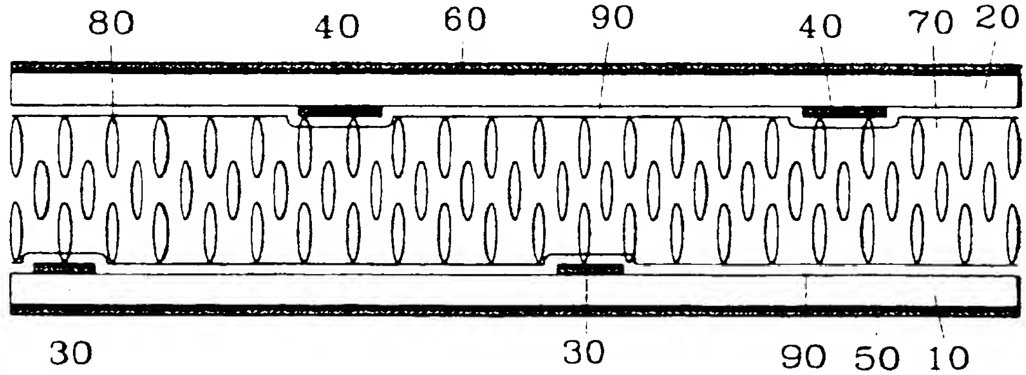
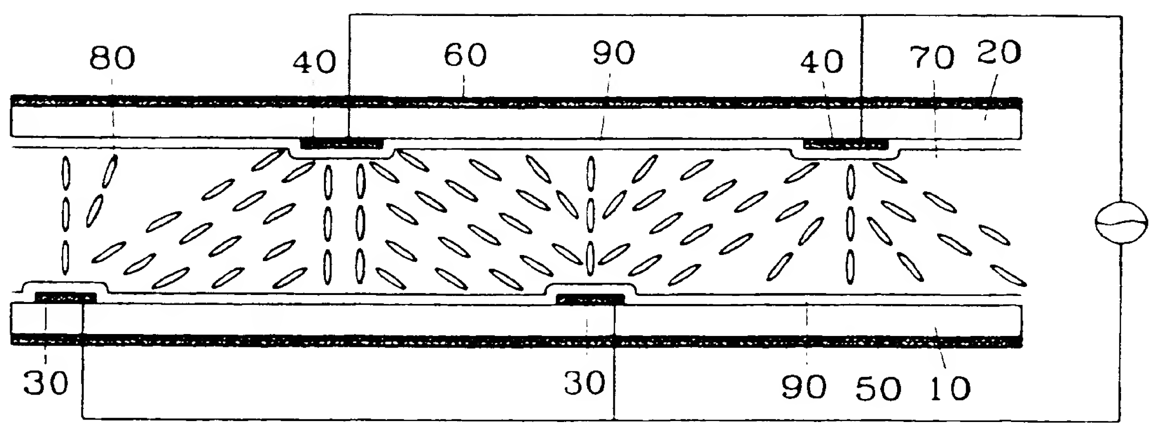


FIG.26B



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LIQUID CRYSTAL DISPLAY

BACKGROUND OF THE INVENTION

(a) Field of the Invention

The present invention relates to a liquid crystal display.

(b) Description of the Related Art

Generally, a conventional liquid crystal display (LCD) includes two substrates having electrodes and liquid crystal injected therebetween. The voltage difference between the electrodes yields an electric field, and the molecules of the liquid crystal are re-arranged by the electric field. The polarization of incident light is varies due to the re-arrangement of the liquid crystal molecules.

Hereinafter, the conventional LCD is explained in detail with reference to the accompanying drawings.

Figs. 1A and 1B are sectional views of a conventional twisted-nematic liquid crystal display (TN-LCD). The TN-LCD in Fig. 1A includes transparent glass substrates 1 and 2 facing each other, a liquid crystal layer 7 inserted between the substrates 1 and 2, and electrodes 3 and 4 formed respectively on the inner surfaces of the substrates 1 and 2, and polarizing plates 5 and 6 for polarizing the light are attached to the outer surfaces of the glass substrates 1 and 2 respectively.

The electrode 3 of the lower substrate 1 is a pixel electrode, the electrode 4 of the upper substrate 2 is a common electrode, and dielectric

anisotropy $\Delta\varepsilon$ of the liquid crystal layer 7 is positive.

In the absence of an electric field, the long axes of the liquid crystal molecules 8 of the liquid crystal layer 7 are parallel to the substrates 1 and 2, and the liquid crystal molecules 8 are twisted spirally from one substrate to the other substrate.

When a power V is connected to the electrodes 3 and 4, and a sufficient electric field is applied to the liquid crystal layer 7 in the direction of the arrow as illustrated in Fig. 1B, the long axes of the liquid crystal molecules 8 are parallel to the direction of the electric field. This type of TN-LCD unfortunately results in having a narrow viewing angle.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a liquid crystal display (LCD) having a wide viewing angle to substantially obviate the problems associated with the related art.

An LCD according to embodiments of the present invention includes a liquid crystal material between first and second substrates, and the liquid crystal molecules are perpendicular to the two substrates. First and second electrodes are formed on one of the two substrates and substantially parallel to each other.

Alignment films for aligning molecular axes of the liquid crystal molecules to be perpendicular to the substrates may be formed on the first and/or the second substrates, and the alignment films may be or may not be

rubbed.

In addition, the LCD of the present invention may further include polarizing plates, and the polarizing directions of the polarizing plates are either parallel or perpendicular to each other.

Here, the dielectric anisotropy of the liquid crystal material may be positive or negative, and the liquid crystal may be at least one among pure nematic liquid crystal, chiral nematic liquid crystal and nematic liquid crystal having chiral dopants.

When voltage is applied to the two electrodes of the LCD of the present invention, a parabolic electric field is generated between the two electrodes, and the liquid crystal molecules are re-arranged in response to the electric field.

The liquid crystal display described above is called an electrically-induced optical compensation liquid crystal display (EOC-LCD) hereinafter.

In the EOC-LCD according to the embodiments of the present invention, the liquid crystal molecules are symmetrically aligned to the surface which is equal distance from each of the electrodes. Accordingly, the phase retardation of the transmitted light is symmetrically compensated, thereby obtaining a wide viewing angle.

The electrodes are preferably bent to form a saw shape in a pixel or by pixel in order to vary the orientations of the liquid crystal molecules.

When using the cross polarizing plates, it is preferable that the polarizing directions of the polarizing plates are neither parallel nor perpendicular to the directions of the electrodes. It is more preferable that the

angle between the polarizing directions of the polarizing plates and the electrodes is 45 degrees.

The bent angle of the electrodes may be between zero and 180 degrees, but it is most preferable that the bent angle of the electrodes is 90 degrees.

Additional objects and advantages of the present invention are set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, illustrate embodiments of the present invention and, together with the description, serve to explain the principles of the invention.

Figs. 1A and 1B are sectional views of a conventional TN-LCD;

Figs. 2A to 2C illustrates a basic driving principle of an EOC-LCD according to a first embodiment of the present invention;

Figs. 3A to 3C illustrate a basic driving principle of an EOC-LCD according to a second embodiment of the present invention;

Fig. 4 is a plan view of an electrode formed in a pixel unit in an EOC-LCD according to a third embodiment of the present invention;

Fig. 5 is a plan view of an electrode formed in a pixel unit in an EOC-

LCD according to a fourth embodiment of the present invention;

Figs. 6 to 16 are graphical illustrations of a viewing angle of an EOC-LCD according to an embodiment of the present invention; and

Fig. 17 is a graphical illustration of electro-optical characteristics in an EOC-LCD according to an embodiment of the present invention.

Figs. 18 to 23 show the shapes of electrodes in the EOC-LCDs according to the embodiments of the present invention;

Fig. 24 shows the arrangement of the liquid crystal molecules at (a) portion in Fig. 23;

Fig. 25 is an exploded perspective view of an LCD according to the embodiment of the present invention; and

Figs. 26A to 26B illustrate a basic driving principle of an EIMD-LCD (electrical induced multi domain mode-LCD) according to the embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will become apparent from a study of the following detailed description when viewed in light of drawings.

Figs. 2A to 2C illustrate a basic driving principle of an EOC-LCD according to a first embodiment of the present invention, and Figs. 3A to 3C illustrate a basic driving principle of the EOC-LCD according to a second embodiment of the present invention.

Referring to Figs. 2A to 2C and 3A to 3C, a pair of transparent glass substrates 10 and 20 having alignment films 90 respectively are formed facing each other. Two linear electrodes 30 and 40 parallel with each other are formed on the inner surface of a lower substrate 10 of the two substrates 10 and 20. The liquid crystal material is injected between the two glass substrates 10 and 20 to form a liquid crystal layer 70. The liquid crystal molecules 80 of the liquid crystal layer 70 are homeotropically aligned and thus are perpendicular to the two substrates 10 and 20. The liquid crystal molecules 80 may have a pre-tilt angle with respect to the two substrates 10 and 20. The two electrodes 30 and 40 may be transparent or opaque conductive material. Two polarizing plates 50 and 60, which polarize the passing light, are attached to the outer surfaces of the glass substrates 10 and 20 respectively.

Generally, one of the two electrodes 30 and 40 is a pixel electrode for applying a different data signal to each pixel unit, and the other is a common electrode for applying a common signal to the entire pixel units. In addition, each pixel electrode is connected to a terminal of a switching device, such as a thin film transistor, formed in each pixel.

The dielectric anisotropy $\Delta\varepsilon$ of the liquid crystal material of the liquid crystal layer 70 should preferably be positive, but it may be negative. The liquid crystal material may be one among nematic liquid crystal, chiral nematic liquid crystal and nematic liquid crystal having left-handed or right-handed chiral dopant.

In addition, one or both alignment films 90 may be rubbed so that the liquid crystal molecules 80 may be inclined in a predetermined direction, or none of the alignment films 90 may be rubbed. The rubbing may be done in an arbitrary direction. However, it is preferable to rub the two alignment films in opposite directions when both of them are rubbed.

The transmission axes of the polarizing plates 50 and 60 are parallel with or perpendicular to each other.

In addition, it is preferable to make the width of the electrodes 30 and 40 between 1 and 10 μm, the distance between the two electrodes 30 and 40 between 2 and 20 μm, and the thickness of the liquid crystal layer 70 between 1 and 15 μm.

In Figs. 2A to 2C, the liquid crystal material is pure nematic liquid crystal which has dielectric anisotropy. In Figs. 3A to 3C, the liquid crystal material is nematic liquid crystal having chiral dopant and positive anisotropy or chiral nematic liquid crystal having positive anisotropy..

Referring to Figs. 2A and 3A, when the electric field is not applied, the liquid crystal molecules 80 of the liquid crystal layer 70 are perpendicular to the two substrates 10 and 20 due to the aligning force of the alignment films 90

The light passing through the polarizing plate 50 attached to the lower substrate 10 passes through the liquid crystal layer 70 without changing its polarization. The same light also passes through the polarizing plate 60 attached to the upper substrate 2 if the transmission axes of the two polarizing plates 50 and 60 are parallel with each other. The same light is blocked by the

polarizing plate 60 of the upper substrate 20 if the transmission axes of the two polarizing plates 50 and 60 are perpendicular to each other.

Figs. 2B and 3B show states of arrangement of the liquid crystal molecules 80 when sufficient electric field is formed, and Figs. 2C and 3C are elevational views thereof. The electric field at points ("boundary-plane") equal distance from each of the two electrodes 30 and 40 is substantially parallel with the two substrates 10 and 20 and is perpendicular to the two electrodes 30 and 40. As the electric field moves away from the points in question and moves toward either one of the electrodes 30 and 40, it curves gradually more downward. That is, the electric field assumes a downward parabolic shape.

Here, the long axis of the liquid crystal molecules 80 is to be aligned along the direction of the electric field since the nematic liquid crystal material has positive dielectric anisotropy. However, the liquid crystal molecules 80 adjacent to the substrates 10 and 20 maintain their original state, in which they are aligned perpendicularly to the substrates 10 and 20 since the aligning force of the alignment film 90 is stronger than the force of the electric field. Accordingly, a liquid crystal director continuously changes to balance the force of the electric field and the aligning force when the pure nematic liquid crystal material is used.

In addition, the liquid crystal material layer has at least two adjacent regions which is between the two electrodes 30 and 40. The liquid crystal molecules 80 in a region are aligned in the same direction, and the liquid crystal molecules 80 in the two regions are aligned symmetrically with respect to the

plane-boundary of the two regions since the electric field between the two electrodes 30 and 40 has parabolic shape as a whole. The plane-boundary is at equal distance from each of the two electrodes 30 and 40 as described above.

Accordingly, referring to Figs. 2B and 2C, a viewing angle in the direction perpendicular to the two electrodes 30 and 40 is enlarged since the phase retardation of the light passing through the liquid crystal layer 70 is symmetrically compensated. The viewing angle in the direction parallel to the electrodes 30 and 40 is also enlarged since the refractive index in the direction of short axes of the liquid crystal molecules 80 has little variation.

On the other hand, since the electric field at the surface equal distance from each of the electrodes 30 and 40 is formed in parallel with the substrates, a discontinuous boundary-plane, in which the liquid crystal molecules do not rotate, is formed at the boundary-plane in question since the force of the electric field is perpendicular to the long axes liquid crystal molecules 80 aligned perpendicularly to the substrates.

Next, as shown in Figs. 3B and 3C, different effects results when the chiral nematic liquid crystal or the nematic liquid crystal having chiral dopant is used instead of the pure nematic liquid crystal as in Figs 2A to 2C. As before, the discontinuous area, in which the liquid crystal molecules 80 do not rotate, is also formed on the boundary-plane equal distance from each of the two electrodes 30 and 40. However, the arrangement of the liquid crystal molecules 80 in both sides of the discontinuous area is not completely

symmetrical to each other since the long axis of the liquid crystal molecules 80 is changed by the force resulting from the electric field and the alignment force as well as the force resulting from chirality.

That is, in Fig. 2C, the long axes of the liquid crystal molecules 80 are aligned perpendicularly to the electrodes 30 and 40 when viewed from the top; in contrast, in Fig. 3C, the liquid crystal molecules 80 in both sides of the discontinuous area may rotate either counterclockwise or clockwise. In this case, a wide viewing angle is obtained in both parallel and perpendicular direction with the electrodes 30 and 40.

In the above state, the polarization of the polarized light passing through the polarizing plate 50 attached to the lower substrate 10 rotates according to the twist of the liquid crystal director as it passes through the liquid crystal layer 70.

In the above two cases, the polarization can be rotated by ninety degrees by controlling the dielectric anisotropy, the gap between the two substrates 10 and 20, or the pitch of the liquid crystal molecules 80. In this case, if the transmission axis of the two polarizing plates 50 and 60 are parallel with each other, the light is blocked out by the polarizing plate 60 attached to the upper substrate 20. If the transmission axis of the two polarizing plates 50 and 60 are perpendicular to each other, the light passes through the polarizing plate 60 of the upper substrate 20.

To summarize, the liquid crystal molecules 80 are arranged symmetrically with respect to the discontinuous area in the EOC-LCD according

to the embodiments of the present invention. Accordingly, the light transmitted in the direction of A and the light transmitted in the direction of B in Figs. 2B and 3B pass through paths made by the similar arrangement of the liquid crystal molecules 80. Accordingly, a wide viewing angle can be obtained since the retardation with respect to the passing light is formed almost in the same way.

The structure and the arrangement of the electrodes may be varied in various ways in the above type of LCD, it is possible to form the electrodes as illustrated in Figs. 4 and 5. Hereinafter, the structure and the arrangement of the electrodes will be explained in detail.

Referring to Figs. 4 and 5, a gate line 100 is horizontally formed and a data line 200 is formed perpendicularly to the gate line 100 in a pixel. A common electrode line, a first horizontal electrode line 32, is formed in parallel with the gate line 100, and a pixel electrode, a second horizontal electrode line 42, is formed in parallel with the first electrode line 32 in each pixel. A thin film transistor (TFT) is formed near a crossing point of the gate line 100 and the data line 200. A first terminal of the TFT is connected to the gate line 100, a second terminal to the data line 300 and a third terminal to the second horizontal electrode line 42.

In Fig. 4, as mentioned above, first and second horizontal electrode lines 32 and 42 are horizontally formed in parallel with each other in each pixel. Given four pixels as a unit, in two pixels in diagonal to each other, e.g., the upper-right and lower-left pixels, first electrodes 33 and second electrodes 43

are formed alternatively therein in parallel to each other. The first and second electrodes 33 and 43 are connected vertically to the first horizontal electrode line 32 and the second horizontal electrode line 42, respectively.

In the remaining two pixels, a first vertical electrode line 31 and a second vertical electrode line 41, which are connected to the first horizontal electrode line 32 and the second electrode line 42 respectively, are formed therein on the opposite sides. In addition, first electrodes 30 are extended from the first horizontal electrode line 32 and the first vertical electrode line 31, and makes a predetermined angle with the first horizontal electrode line 32 and the first vertical electrode line 31. Second electrodes 40 extended from the second horizontal electrode line 42 and the second vertical electrode line 41 are formed in parallel with the first electrodes 30, and each of second electrode 40 is arranged between two first electrodes 30.

As a result, the first and second electrodes 33 and 43 in a pixel are not parallel with the first and second electrodes 30 and 40 in the adjacent pixel, and make a predetermined angle with respect to each other.

In Fig. 5, the first and second horizontal electrode lines 32 and 42 are horizontally formed in parallel with each other in each pixel. The first and second vertical electrode lines 31 and 41 are vertically extended from the opposite ends of the first and the second horizontal electrode lines 32 and 42, respectively. First electrodes 36 consist of first portions 34 and second portions 35; the first portions 34 extends vertically downward from the first horizontal electrode line 32, and second portions 35 connected to the first

portions 34 are bent towards right. A part of the first vertical electrode line 31 also serves as the first portions 34 of the first electrodes 36, and a plurality of branches 37 extended from the first vertical electrode line 31 are formed in parallel with the second portion 35.

Second electrodes 46 consist of first portions 44 and second portions 45; the first portions 44, extended from the second horizontal electrode line 42 and the second vertical electrode line 41, are formed between and in parallel with the second portions 35 of the first electrodes 36; the second portions 45 extended from the first portions 44 are formed in parallel with the first portions 34 of the first electrodes 36. A part of the second vertical electrode line 41 serves also as the second portions 45 of the second electrode 46. That is, the first and second electrodes 36 and 46, which are in parallel with each other, are bent in each pixel.

As described above, the long axes of the liquid crystal molecules are aligned in many directions by forming the electrode in various directions in a pixel unit or in a pixel, thereby obtaining a wide viewing angle.

Hereinafter, the examples of the EOC-LCD according to embodiments of the present invention are explained in detail.

EXAMPLE 1

The nematic liquid crystal having chiral dopant and the pure nematic liquid crystal were used as the liquid crystal layer 70, and the resulting viewing angles were measured for each case.

The refractive anisotropy Δn of the liquid crystal layer 70 was 0.09, the

thickness d of the liquid crystal layer 70 was 4.5 μm, and the alignment films 90 were not rubbed. In addition, the two electrodes 30 and 40 were horizontally formed, and the transmission axes of the polarizing plates 50 and 60 attached to the outward surfaces of the two substrates 10 and 20 were formed to have an angle of 90° with respect to each other. The transmission axis of one polarizing plate were formed to have an angle of 45° with respect to the two electrodes 30 and 40, and the transmission axis of the other polarizing plate were formed to have an angle of 135° with respect to the two electrodes 30 and 40. The angles have been measured by setting the right side of the horizontal direction as zero degree.

Fig. 6 is a graphical illustration of viewing angles of the EOC-LCD obtained when nematic liquid crystal having chiral dopant of 0.1% was used. Viewing angles of 80° in the horizontal direction and 76° in the vertical direction were measured for a contrast ratio 10.

Fig. 7 is a graphical illustration of viewing angles of the EOC-LCD when pure nematic liquid crystal was used. Viewing angles of 76° in the horizontal direction and in the vertical direction were measured for a contrast ratio 10.

The viewing angle of over 120° was measured in a diagonal direction for both cases when the contrast ratio was set to 60.

EXAMPLE 2

While maintaining the same condition as in example1, the alignment

films 90 formed on the two substrates 10 and 20 were rubbed, and the resulting viewing angles were measured in each case.

Fig. 8 is a graphical illustration of a viewing angle of the EOC-LCD obtained when the alignment film 90 formed on the upper substrate 20 was rubbed in the angle of 135 ° and when the alignment film 90 formed on the lower substrate 10 is rubbed in the angle of 315 ° .

Fig. 9 is a graphical illustration of viewing angles of the EOC-LCD obtained when the alignment film 90 formed on the upper substrate 20 was rubbed in the angle of 45 ° and the alignment film 90 formed on the lower substrate 10 was rubbed in the angle of 225 ° .

As shown in Figs. 8 and 9, more uniform viewing angle can be obtained since the difference between the viewing angles in the horizontal and the vertical direction and the viewing angle in the diagonal direction can be reduced by rubbing the alignment films as described above.

EXAMPLE 3

While maintaining the same condition as in example 1, the viewing angle was measured by varying the orientations of the polarizing plates 50 and 60 attached to the outward surfaces of the two substrates 10 and 20.

Fig. 10 is a graphical illustration of viewing angles of the EOC-LCD obtained by arranging the transmission axis of the polarizing plates 60 attached to the outward surface of the upper substrates 20 to make an angle of 45 ° with respect to the direction of the two electrodes 30 and 40, and by arranging

the transmission axis of the polarizing plate 50 attached to the lower substrate 10 to make an angle of 135° with respect to the direction of the two electrodes 30 and 40.

Fig. 11 is a graphical illustration of viewing angles of the EOC-LCD obtained by arranging the transmission axis of the polarizing plates 60 attached to the upper substrates 20 to make an angle of 30°, and by arranging the transmission axis of the polarizing plate 50 attached to the lower substrate 10 to make an angle of 120°.

As described in example 1, the viewing angle of over 120° was measured in the four directions of the diagonal line for the contrast ratio 60, and the viewing angle of 80° was measured in every direction for the contrast ratio 10 in Fig. 10. When comparing the results of Fig. 10 and Fig. 11, the viewing angle depends on the angle between the electrodes and the transmission axis of the polarizing plate. Accordingly, an almost uniform viewing angle can be obtained in every direction by adjusting the direction of the electrodes and the direction of the transmission axis of the polarizing plates in various ways.

EXAMPLE 4

While maintaining the same conditions as in example 1, the viewing angle was measured when negative uniaxial compensation film 100 were attached to the outer surfaces of the two substrates 10 and 20 as illustrated in Fig 12. The compensation film was used for compensating the residual phase difference of the retardation.

As shown in Fig. 13, when the compensation film 100 was not used, the viewing angle of 80 ° was measured. Fig. 14 shows the viewing angle measured when the compensation film 100 having the retardation value of 40nm was used. Fig. 15 shows the viewing angle measured when the compensation film 100 having the retardation value of 80nm was used. Fig. 16 shows the viewing angle measured when the compensation film 100 having the retardation value of 120nm was used.

In Figs. 14 to 16, the viewing angle were increased to 60 ° for the contrast ratio 10 when the compensation film 100 was used.

From the above results, it can be seen that the viewing angle of over 60 ° can be obtained in every direction by optimizing the gap between the two substrates 10 and 20 and the retardation value of the compensation film 100. The retardation value of the compensation film should preferably be 30 to 500 nm.

Although the embodiments of the present invention uses a negative uniaxial compensation film, a positive uniaxial compensation film, a biaxial compensation film, a compensation film having a hybrid structure, or a compensation film having a twisted structure may be used.

In addition, although the compensation films 100 are attached to the two substrates 10 and 20 in the embodiment of the present invention, it may be attached to only one substrate.

EXAMPLE 5

The electric-optical characteristics were measured. The pure nematic

liquid crystal was used as the liquid crystal layer 70, the alignment films 90 were not rubbed, and the width of the two electrodes 30 and 40 was 5 μm respectively.

Fig. 17 is a graphical illustration of relation among the gap between the two substrates, the distance between the two electrodes and the driving voltage according to an embodiment of the present invention.

Here, V_{max} is the driving voltage for obtaining the maximum transmittance, T_{max} is the maximum transmittance, t_{on} is a response time of the liquid crystal molecules when power is turned ON, t_{off} is the response time of the liquid crystal molecules when power is turned OFF, $t_{tot} = t_{on} + t_{off}$, V_{10} is the driving voltage when the transmittance has 10% of the maximum value, and V_{90} is the driving voltage when the transmittance has 90% of the maximum value.

In Fig. 17, the driving voltage for obtaining the maximum transmittance is 6 to 30V when the gap between the two substrates 10 and 20 is between 3 and 6 μm, and the distance between the two electrodes 30 and 40 is 8 or 10 μm.

As described above, the driving voltage can be lowered by properly controlling the distance between the electrodes and the gap between the two substrates.

In the EOC-LCD according to embodiments of the present invention, the two electrodes are formed in one of the two substrates, the liquid crystal molecules are aligned perpendicularly to the electrodes, and the liquid crystal director is driven by the electric field formed in the shape of parabola between

the two electrodes. Here, the liquid crystal molecules of the liquid crystal layer on the boundary-plane equal distance from each of the two electrodes are aligned symmetrically. Accordingly, the wide viewing angle can be obtained since the retardation of the light is symmetrically compensated.

It is preferable to form the electrodes having a saw shape in a pixel or by pixel as illustrated in Figs. 18 and 23, whereby a very good display characteristic can be obtained. Hereinafter, the structure and the arrangement of the electrodes in rectangular pixels will be explained in detail.

As shown in Figs. 18 and 19, a first electrode line 32, which is a common electrode line, and a second electrode line 42, which is a pixel electrode line, are parallel to each other in each pixel.

In the embodiment of the present invention illustrated in Fig. 18, the first and the second electrode lines 32 and 42 facing each other in each pixel are extended in alternate directions along the rows of the pixels, for example, the first in the transverse direction, the second in the longitudinal direction, the third in the transverse direction, and so on. On the contrary, the electrode lines 32 and 42 are extended in the same direction along the columns of the pixels. First and second electrodes 33 and 43 parallel to each other are arranged alternately, and extended from the first and the second electrode lines 32 and 42 respectively.

In the embodiment of the present invention illustrated in Fig. 19, the first and the second electrode lines 32 and 42 facing each other in parallel are extended in alternate directions along both the rows and the columns of the

pixels, and thus electrode lines in all pixels adjacent to a pixel having a transverse electrode line are extended in the longitudinal direction.

In the embodiments of the present invention illustrated in Figs. 20 and 21, the first electrode and the second electrode are extended diagonally in each pixel.

As illustrated in Figs. 20 and 21, the first electrode lines 32, have the shape of either '┐' or '└' which is made by extending the electrode lines to the transverse and the longitudinal directions from one peak in the pixels. The second electrode lines 42 have the shape of either '└' or '┐' which is made by extending electrode lines to the transverse and the longitudinal directions from another vertex facing the above mentioned vertex diagonally. The first and the second electrodes 32 and 33 have a rotational symmetry with respect to a diagonal of a pixel.

The first electrodes 33 and the second electrodes 43 parallel to each other are extended from the first electrode line 32 and the second electrode line 42 in directions making angles with the electrode lines 32 and 33, and they are arranged alternately. In the embodiment of the present invention illustrated in Fig. 20, the electrodes 33 and 43 in a pixel makes an angle with the electrodes 33 and 34 in the adjacent pixels along the rows of the pixels, and the first electrode 33 and the second electrode 43 in the same column are extended in the same direction. On the other hand, in the embodiment of the present invention illustrated in Fig. 21, the electrodes 33 and 43 in a pixel makes an angle with those in the adjacent pixels along both the rows and the columns of

the pixel.

In the embodiment of the present invention as illustrated in Fig. 22, the pixels have parallelogram shapes.

As illustrated in Fig. 22, first electrode lines 32, which are the common electrode lines, and second electrode lines 42, which are the pixel electrode lines, are parallel to each other and extended in the transverse direction. The first electrodes 33 and the second electrodes 43, connected respectively to the first and the second electrode lines 42 and 43 are arranged alternately and parallel to each other , and their extending directions are neither the transverse direction nor the longitudinal direction. The lengths of the electrodes are the same, and thus the pixels have parallelogram shapes. The electrodes 33 and 43 in a row are extended in the same direction, and, however, the electrodes 33 and 43 in adjacent rows are extended in the different directions. For example, as shown in Fig. 22, the electrodes 33 and 43 in the first row are slanted to the right with respect to the directions perpendicular to the electrode lines 32 and 42, but those in the second row are slanted to the left. Accordingly, the first electrode 33 and the second electrode 43 form a saw shape along the rows of the pixel.

In the embodiment of the present invention as illustrated in Fig. 23, the pixel itself has the saw shape.

As illustrated in Fig. 23, each pixel has the saw shape, a central portion of the pixel being bent. A first electrode line 32, which is the common electrode, and a second electrode line 42, which is the pixel electrode, are

formed parallel to each other in each pixel, and they face each other.

The first electrodes 33 and the second electrodes 43 connected respectively to the first electrode line 32 and the second electrode line 42 are alternately arranged and they are parallel to each other. The first electrodes 33 and the second electrodes 43 have the saw shape, the central portion in the pixel being bent.

Fig. 24 is an enlarged view of a bent portion (a) of the electrodes in Fig. 23.

The liquid crystal molecules 80 are driven by the electric field having a parabolic shape when voltage is applied to the first electrode 33 and the second electrode 43. As shown in Fig. 10, a projection of the liquid crystal molecules 80 onto the substrate is perpendicular to the electrodes 33 and 34, and the liquid crystal molecules 80 rise upward in the head of an arrow in Fig. 10. Accordingly, the arrangement of the liquid crystal molecules 80 is symmetrical with respect to the boundary plane C-C. Two pairs of two regions, which are symmetrically aligned on the basis of the boundary plane C-C at both sides of the bent portion, are formed since the electrodes 33 and 43 are bent in the saw shape. Therefore, the LCD has four regions, in which alignments of the liquid crystal molecules 80 are different from one another.

The polarizing directions of the polarizing plates 50 and 60 may be any directions, but is preferable that they are neither parallel to nor perpendicular to a part of the first and the second electrodes 33 and 43. In particular, the display characteristic is the best when the angle formed by the polarizing

directions of the polarizing plates 50 and 60 and the electrodes 33 and 43 is 45 degrees.

The bent angle of the first and the second electrodes 33 and 43 having the saw shape may be within a range between 0 to 180 degrees, and it is related to the polarizing directions of the polarizing plates 50 and 60. When the electrodes make an angle of 45° to the polarizing direction, the best viewing angle characteristics may be obtained. In this case, the bent angle of the electrodes 33 and 43 is 90°.

In order to compensate residual phase difference due to the retardation of light, a phase difference compensation film may be attached to the outside of the LCD in accordance with the embodiments of the present invention.

Fig. 25 is an exploded perspective view of an LCD according to the embodiment of the present invention, to which compensation films are attached.

As illustrated in Fig. 25, compensation films 110 are attached between a liquid crystal cell 100 and polarizing plates 50 and 60. The LCD in Fig. 25 has two sheets of the compensation films 110, each being attached between each side of the liquid crystal cell 100 and each polarizing plate 50 or 60 respectively. However, the LCD may have only a compensation film 110 being attached between either of the two sides of the liquid crystal cell and either of the polarizing plates 50 and 60, and the LCD may have at least three sheets of compensation films. A uniaxial or a biaxial compensation film may be used as the compensation film, and a combination of the uniaxial compensation film and the biaxial compensation film may be used.

The electrodes 33 and 43 having the saw shape illustrated in Figs. 18 to 23 may be adapted to the LCDs of another mode in which the liquid crystal material is driven by the two electrodes parallel to each other. For example, it can be adapted to an in-plane switching (IPS) mode or an electrical induced multi domain (EIMD) mode.

Hereinafter, the IPS-LCD and EIMD-LCD are explained in detail.

In the IPS-LCD, the two electrodes, being parallel to each other, are formed on one substrate as the EOC-LCD. Here, the dielectric anisotropy $\Delta\varepsilon$ of the liquid crystal material may be positive or negative.

In the absence of the electric field, the long axes of the liquid crystal molecules are parallel to the substrates 10 and 20, and are aligned in the direction being parallel to or making a predetermined angle with the electrodes 33 and 43. When sufficient electric field is applied to the liquid crystal material, the electric field, which is substantially parallel to the substrate, is generated, whereby the long axes of the liquid crystal molecules 80 in the central portion of the liquid crystal layer are aligned substantially parallel to the electric field. However, the liquid crystal molecules 80, which are positioned from the substrates 10 and 20 to the central portion of the liquid crystal layer, are spirally twisted since the liquid crystal molecules 80 around the substrates 10 and 20 keep their original orientations by an aligning force.

In the EIMD-LCD, a plurality of first electrodes and second electrodes, being parallel to each other, are formed alternately on each substrate

Figs. 26A and 26B are schematic views of a principle of the EIMD-LCD

according to the embodiment of the present invention.

As illustrated in Figs. 26A and 26B, a pair of transparent glass substrates 10 and 20, on which alignment films 90 are formed respectively, face each other in a parallel manner. A first linear electrode 30 and a second linear electrode 40 parallel to each other are formed respectively on the inner surface of the substrates 10 and 20, and they are arranged alternately. The liquid crystal material is injected between the two glass substrates 10 and 20, thereby forming a liquid crystal layer 70, and the liquid crystal molecules 80 in the liquid crystal layer 70 are aligned perpendicularly to the two substrates 10 and 20. In addition, the polarizing plates 50 and 60 are attached to outsides of the two substrates 10 and 20 respectively.

It is preferable that the dielectric anisotropy $\Delta\epsilon$ of the liquid crystal material of the liquid crystal layer 70 is positive, however, the dielectric anisotropy $\Delta\epsilon$ may be negative.

As illustrated in Fig. 26A, in the absence of the electric field, the liquid crystal molecules 80 in the liquid crystal layer 70 is aligned perpendicularly to the two substrates 10 and 20 by the aligning force of the alignment film 90.

Figs. 26A and 26B are views of the EIMD-LCD when a sufficient electric field is present in the LCD. The electric field having the inclination angle with respect to the direction perpendicular to the two substrates 10 and 20 is formed by the first and the second electrodes 30 and 40 when the sufficient electric field is present in the LCD. This electric field is formed symmetrically with respect to a plane which is perpendicular to the two

substrates 30 and 40 and passes through the two electrodes 30 and 40. In case of a nematic liquid crystal material having positive dielectric anisotropy, the long axes of the liquid crystal molecules 80 is aligned along the direction of the electric field due to the electric field having the above-mentioned inclination direction.

In the above-mentioned IPS-LCD and EIMD-EOC likewise the EOC-LCD, the electrodes 30 and 40 are formed in the saw shape and the retardation of the light is compensated by the regions in which the inclination directions of the liquid crystal molecules are different from each other, thereby obtaining the wide viewing angle.

In the liquid crystal display according to the preferred embodiment of the present invention, the two electrodes are formed in the two substrates, the liquid crystal molecules are aligned perpendicularly, and a liquid crystal director is driven by the electric field in the shape of parabola between the two electrodes. Here, the liquid crystal molecules of the liquid crystal layer in both sides of the boundary plane surface are symmetrically formed. Accordingly, the retardation of the projected light is symmetrically compensated, thereby obtaining the wide viewing angle. In addition, a wider viewing angle may be obtained since four regions of which the alignment directions of the liquid crystal molecules are different from one another by forming the electrodes in the saw shape.

Other embodiments of the invention will be apparent to the skilled in the art from consideration of the specification and practice of the invention

disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

WHAT IS CLAIMED IS:

1. A liquid crystal display, comprising:

a first substrate and a second substrate facing each other;

a liquid crystal material layer injected between the first and the second substrates and aligned homeotropically; and

at least two electrodes parallel with each other formed on either the first or the second substrate.

2. The liquid crystal display of claim 1, wherein the liquid crystal material layer has positive dielectric anisotropy.

3. The liquid crystal display of claim 2, wherein the liquid crystal material layer is a material selected from the group consisting of chiral nematic liquid crystal material, nematic liquid crystal material and nematic liquid crystal material having chiral dopant.

4. The liquid crystal display of claim 1, further comprising polarizing plates attached to surfaces of the first and the second substrates respectively.

5. The liquid crystal display of claim 4, further comprising alignment films formed on the first and the second substrates for aligning liquid crystal molecular axes of the liquid crystal material layer perpendicularly

to the substrates.

6. The liquid crystal display of claim 5, wherein transmission axes of the polarizing plates are perpendicular to or in parallel with each other.

7. The liquid crystal display of claim 6, wherein the liquid crystal molecules of the liquid crystal material layer have a pre-tilt angle.

8. The liquid crystal display of claim 7, wherein the difference is below 30V between a driving voltage applied to the electrodes when the light passing through the liquid crystal material layer and the polarizing plates has the maximum transmittance and a driving voltage applied to the electrode when the light passing through the liquid crystal material layer and the polarizing plates has the minimum transmittance .

9. The liquid crystal display of claim 1, wherein the electrodes in the adjacent pixels are directed in different directions with respect to each other.

10. The liquid crystal display of claim 1, wherein the electrodes in a pixel unit are bent.

11. The liquid crystal display of claim 1, wherein the width of the electrodes is between 1 and 10 μm.

12. The liquid crystal display of claim 11, wherein the distance between the electrodes is between 2 and 20 μm.

13. The liquid crystal display of claim 12, wherein the gap between the first and the second substrates is between 1 and 15 μm.

14. The liquid crystal display of claim 13, wherein the gap between the first and the second substrates is between 3 and 10 μm.

15. The liquid crystal display of claim 14, wherein the gap between the first and the second substrates is between 3 and 6 μm.

16. The liquid crystal display of claim 13, wherein one or both of the alignment film is rubbed.

17. The liquid crystal display of claim 4, further comprising compensation films inserted between the first or the second substrate and the polarizing plates.

18. The liquid crystal display of claim 17, wherein the compensation film has a structure selected from the group consisting of positive uniaxial, negative uniaxial, biaxial, a hybrid and a twisted structure.

19. The liquid crystal display of claim 18, wherein the retardation value of the compensation film is between 30 and 500nm.

20. A liquid crystal display, comprising:

a first substrate and a second substrate facing each other;

a liquid crystal material layer injected between the first and the second substrates and initially aligned homeotropically;

means for varying directions of long axes of molecules of the liquid crystal material layer, wherein the liquid crystal material layer has at least two adjacent regions, the molecules in any one region of the adjacent regions are aligned in the same direction, and the molecules in the two regions are aligned symmetrically with respect to the plane-boundary of the two regions.

21. A liquid crystal display having at least one pixel, comprising:

a first substrate and a second substrate facing each other;

a liquid crystal material layer injected between the first and the second substrates; and

at least two linear electrodes being parallel to each other and formed on the first or the second substrate, each electrode having a first portion and a second portion which are not parallel to each other.

22. The liquid crystal display of claim 21, wherein the electrodes

are formed on either the first substrate or the second substrate.

23. The liquid crystal display of claim 22, wherein liquid crystal molecules of the liquid crystal material layer is substantially perpendicular to the first substrate and the second substrate when the voltage difference between the electrodes is substantially zero.

24. The liquid crystal display of claim 23, wherein the liquid crystal material layer has positive dielectric anisotropy.

25. The liquid crystal display of claim 24, wherein the liquid crystal material layer is selected from the group consisting of chiral nematic liquid crystal material, nematic liquid crystal material and nematic liquid crystal material having chiral dopant.

26. The liquid crystal display of claim 25, further comprising alignment films formed on the first and the second substrates for aligning liquid crystal molecular axes of the liquid crystal material layer perpendicularly to the substrates.

27. The liquid crystal display of claim 22, wherein liquid crystal molecules of the liquid crystal material layer are substantially parallel to the first substrate and the second substrate when the voltage difference between the

electrodes is substantially zero.

28. The liquid crystal display of claim 27, further comprising alignment films formed on the first and the second substrates for aligning liquid crystal molecular axes of the liquid crystal material layer parallel to the substrates.

29. The liquid crystal display of claim 21, wherein the electrodes are formed alternately on the first substrate and the second substrate.

30. The liquid crystal display of claim 29, wherein liquid crystal molecules of the liquid crystal material layer is substantially perpendicular to the first substrate and the second substrate when the voltage difference between the electrodes is substantially zero.

31. The liquid crystal display of claim 30, wherein the liquid crystal material layer has positive dielectric anisotropy.

32. The liquid crystal display of claim 31, further comprising alignment films formed on the first and the second substrates for aligning liquid crystal molecular axes of the liquid crystal material layer perpendicularly to the substrates.

33. The liquid crystal display of claim 21, wherein the angle formed by the first portion and the second portion of the electrodes is larger than zero and smaller than 180 degrees.

34. The liquid crystal display of claim 33, wherein the angle formed by the first portion and the second portion of the electrodes is 90 degrees.

35. The liquid crystal display of claim 21, wherein the liquid crystal display has at least two pixels, and the first portion and the second portion of the electrodes are formed in adjacent pixels respectively.

36. The liquid crystal display of claim 35, wherein the first portion and the second portion of the electrodes are not connected.

37. The liquid crystal display of claim 21, wherein the first portion and the second portion of the electrodes are formed in one pixel.

38. The liquid crystal display of claim 37, wherein the first portion and the second portion of the electrodes are connected.

39. The liquid crystal display of claim 21, wherein the width of the electrodes is between 1 and 10 μm.

40. The liquid crystal display of claim 39, wherein the distance between the electrodes is between 2 and 20 μm.

41. The liquid crystal display of claim 21, wherein the gap between the first and the second substrates is between 1 and 15 μm.

42. The liquid crystal display of claim 21, further comprising polarizing plates attached to outer surfaces of the first and the second substrates respectively.

43. The liquid crystal display of claim 42, wherein polarizing directions of the polarizing plates are either perpendicular or parallel to each other.

44. The liquid crystal display of claim 43, wherein the polarizing directions of the polarizing plates are neither parallel nor perpendicular to the first portion and the second portion of the electrodes.

45. The liquid crystal display of claim 44, wherein the angle made by the polarizing directions of the polarizing plates and the first portion and the second portion of the electrodes is 45 degrees.

46. The liquid crystal display of claim 45, further comprising at least

one compensation film attached to the first or the second substrate.

47. The liquid crystal display of claim 46, wherein the compensation film is selected from the group consisting of a positive uniaxial, a negative uniaxial and a biaxial compensation film.